Change in the Composition of Molluscan Shell Assemblage Washed up on the Shore in Amami Island, Japan

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ABSTRACT Molluscan shells washed up on the shore in Amami Island, south of Kyûshû were quantitatively sampled by beachcombing and sand-sorting on the strandline in 1979 and 1988, between which a lagoon near the sampling sites was landfilled for construction of a new airport. In all the samples, the most dominant part was occupied by gastropods, most of which were free-living epiphytes in the intertidal or subtidal zone. Between the two years, the proportions of interstitial detritus feeders, e.g., Caecids, and grazers of colonial animals, e.g., Triphorids, decreased. Data on the composition of the number of individuals per family were used for a principal component analysis. The trend in the variation of the shell assemblages between the two years coincided with the gradient of environmental disturbance. This suggests that changes in the composition of molluscan shell assemblage resulted from deterioration of the coral reef ecosystem, caused by human activities.

KEY WORDS molluscan shell assemblage/ sand-sorting/ Amami Island/ coral reef/ human impact

Introduction

It is very difficult to study community structure of coastal molluscan fauna because the diversity in their habitats and life forms is so great that there are no appropriate methods of sampling them. In contrast, shells washed up on the shore, which can be easily sampled, have not yet been investigated as a subject of community ecology because it has generally been believed that there are interfering factors such as a selective transportation (Martin-Kaye, 1951; Lever, 1958; Lever and Thijssen, 1968) and selective damage (Vermeij, 1974). The selection process, however, is thought to remain roughly constant as long as geological and physical conditions are unchanged. Thus, quantitative sampling of molluscan shells washed up on the shore will be useful for analyzing long term change in composition of shell assemblages.

In 1979, I conducted quantitative sampling of shells on the sandy beach of Tsuchihama, Amami Island, south of Kyûshû. After 1983, near Tsuchihama, a lagoon housing a coral reef was landfilled for construction of a new airport. The corals around the new airport were killed probably by turbidity caused by the construction. To investigate the effect of the environmental change caused by human impact on these coastal molluscan fauna, I tried sampling in 1988 in the same method. In this report, it is intended at first to describe the molluscan shell assemblages of 7 samples, and next, an analysis will be made by sorting the shells into habitat, mobility, feeding habit and food menu. Finally, the data on the composition of the shell assemblages are used for principal component analysis and discussed from the standpoint of the effect of environmental change.

Materials and Methods

The investigations were carried out on the sandy beaches of Tsuchihama and Wano, Kasari-cho, in the northern part of Amami Island, which is located about 350 km south of Kyûshû Island (28° 25' N, 129° 42' E, Fig. 1). Tsuchihama beach runs approximately west to east, with the sea on the southern side. The coast around the beach was fringed with the coral reef; the reef was near the northern limit of surviving coral reef in Japan. There are a few small rivers, which become underflows near the river mouths.

The beach of Tsuchihama was famous for the abundance of molluscan shells washed up on the shore, and many new species of minute molluscs had been described from the beach material (Kosuge, 1961 - 63; Habe, 1978; Hinoide and Habe, 1978). A part of the lagoon of the coral reef near Wano was landfilled for construction of a new airport in 1984.

I sampled molluscan shells washed up on the shore by the following two methods: (1) Beachcombing: I collected all the moderate-sized (approximately > 5 mm) shells which had recently died (color and/ or gloss of periostracum are still remaining at least in part) from the strandline between sites A and P in Fig. 1. (2) Sand-sorting: I stroked a strandline which contained many minute shells by hand, and sampled > 0.3

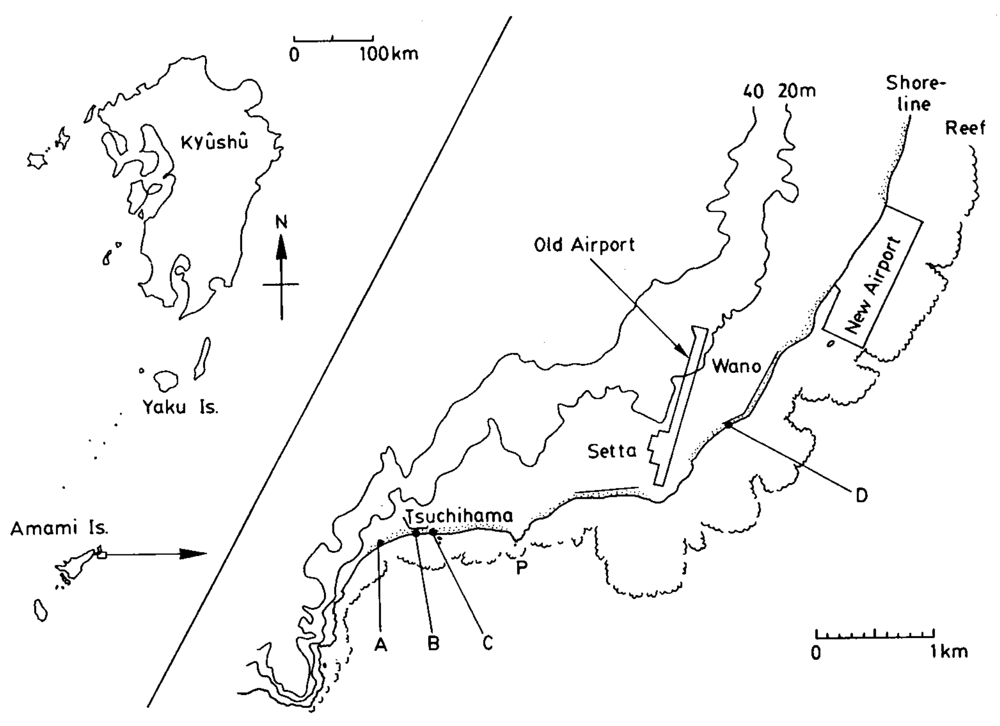

Fig. 1. Map of study sites in Amami Island. Samples for sand-sorting was collected at sites A, B, C and D. Beachcombing was conducted between sites A and P.

Table 1. Methods, sites, dates and intensities of samplings.

Code	Method	Site	Date	Intensity[1]
B-1	beachcombing	between A and P	Dec. 20-21, 1979	9 hrs
B-2	beachcombing	between A and P	Dec. 31, 1988-Jan. 1, 1989	6 hrs
S-1	sand-sorting	B	Dec. 20, 1979	0.5 kg
S-2	sand-sorting	A	Dec. 31, 1988	0.3 kg
S-3	sand-sorting	B	Dec. 31, 1988	0.3 kg
S-4	sand-sorting	C	Dec. 31, 1988	0.3 kg
S-5	sand-sorting	D	Dec. 31, 1988	0.3 kg

[1] Sampling intensities are represented as the time spent in beachcombing or as the weight of the sand inspected.

kg of the sand. From a definite weight of sand, I sorted out all the unbroken, less polished shells. The codes, dates and the sites of the sampling are summarized in Table 1.

All the shells collected were sorted by species. The classification of higher taxa was based on Golikav and Starobogatov (1975) for Gastropoda excluding Discopoda, Ponder (1985) for Discopoda, Habe (1977) for Bivalvia, and Powell (1979) for others.

Results

All the species of shell collected belonged to 123 families, 36 orders, 10 subclasses and 4 classes (Table 2). Size, habitat, mobility, feeding habit and food are also shown in Table 2. The numbers of species and individuals for each family are listed in Table 3. The total numbers of species in B-1, B-2, S-1, S-2, S-3, S-4 and S-5 were 325, 356, 336, 318, 308, 259 and 153, respectively. In both the beachcombing samples, Cypraeidae, Cerithiidae, Triphoridae, Muricidae, Mitridae and Conidae contained more than 10 species. In all the 5 sand-sorting samples (S1 - S5) , Ressoidae, Cerithiidae, Triphoridae and Turridae contained more than 10 species. The total numbers of individuals in B-1, B-2, S-1, S-2, S-3, S-4, and S-5 were 2174, 1529, 3389, 1751, 1358, 781 and 695. In all the 7 samples, > 75 % of the total number of shells belonged to Gastropoda (Table 4).

Table 5 summarizes the shell composition along with different types of habitat. In all the samples, epiphytes in the inter/sub-tidal zone dominated the assemblages, although many of the epiphytes are sometimes endophytic or cryptic Epiphytes in fresh/brackish water, e.g., Thiarid and Lymnaeid shells, were collected in B-1, B-2, S-1 and S-5.

Table 6 shows the composition of shells with different types of mobilities. In all the samples, free-living species dominated the assemblages.

The composition of shells with different feeding habits are shown in Table 7. The percentages of carnivores and detritus feeders in the beachcombing samples were higher and lower, respectively, than in sand-sorting samples. The percentages of

Table 2. Ecological properties of shelled molluscs collected in the seven samplings in Table 1.

CLASS Subclass	Order	Family	Family Code	Size[1]	Habitat[2]	Mobility[3]	Feeding Habit[4]	Food[5]
POLYPLACOPHORA	Ischnochitonida	Chitonidae	PO1	2,3,4	Ep	F	H	A
GASTROPODA								
Cyclobranchia	Docoglossa	Patellidae	C1	3,4	Ep	F	H	A
		Acmaeidae	C2	1,2,3,4	Ep	F	H	A
		Lottiidae	C3	3,4	Ep	F	H	A
Scutibranchia	Dicranobranchia	Emarginulidae	S1	1,2,3	Ep	F	H	A,S
		Hemitomidae	S2	1,2,3	Ep	F	H	A
		Fissurellidae	S3	1,2,3	Ep	F	H	A
	Fissobranchia	Scissurellidae	S4	1	Ep	F	H	A,S
		Haliotidae	S5	3,4,5	Ep	F	H	A
Pectinibranchia	Anisobranchia	Turbinidae	P1	1,2,3,4	Ep	F	H	A
		Liotiidae	P2	1,2,3	Ep	F	H	A
		Skeneidae	P3	1	Ep,I	F	H	A
		Phasianellidae	P4	1	Ep	F	H	A
	Trochoidea	Angariidae	P5	4	Ep	F	H	A
		Trochidae	P6	1,2,3,4,5	Ep	F	H	A
		Umboniidae	P7	2,3,4	En	F	D	D
		Stomatellidae	P8	1,2,3,4	Ep	F	H	A
	Planilabiata	Neritopsidae	P9	4	Ep	F	H	A
		Neritidae	P10	1,2,3,4	Ep	F	H	A
		Phenacolepadidae	P11	2,3	Ep	F	D	D
	Ectobranchia	Tornidae	P12	1,2	En,I	F	D	D
		Vermetidae	P13	3,4,5	Ep	A	F	P
	Protopoda	Siliquariidae	P14	3,4,5	Ep	A	F	P
	Discopoda	Littorinidae	P15	1,2,3	L	F	H	A
		Assimineidae	P16	1,2	L	F	H	A
		Rissoidae	P17	1,2	EP,I	F	H,D	D
		Caecidae	P18	1	I	F	D	D
		Rissoellidae	P19	1	Ep	F	H	A
	Alata	Strombidae	P20	3,4,5,6	En	F	H	A
	Heteropoda	Atlantidae	P21	1	P	F	C	P
	Canalifera	Cymatiidae	P22	2,3,4,5	Ep	F	C	Po
		Colubrariidae	P23	3,4,5	Ep	F	C	Po
	Echinospirida	Ranellidae	P24	2,3,4,5	Ep	F	C	Po
		Fossaridae	P25	1,2	Ep	F	H	A
		Vanicoroidae	P26	2,3	Ep	F	H	A

1 1, 0 - 5 mm; 2, 5 - 10 mm; 3, 10 - 20 mm; 4, 20 - 40mm; 5, 40 - 80 mm; 6, >80 mm.
2 E, epiphytic in sub- and littoral zone; F, epiphytic in fresh/ brackish water zone; I, interstitial in sub- and littoral zone; L, epiphytic in supra-littoral zone; N, endophytic in sub-and littoral zone; P, planktonic.
3 F, free living; S, stationary; A, attaching to substrata.
4 C, carnivore; D, detritus feeder; F, filter feeder; G, grazer of colonial animals; H, herbivore; P, parasite; S, scavenger; Z, symbiotic with zooxanthellae.
5 A, algae; B, Bivalvia; C, Cnidaria; Ci, Cirripedia; D, detritus; E, Echinodermata; G, Gastropoda; M, dead or decaying animal matter; P, plankton; Po, Polychaeta, Sipuncula or Nematoda; S, Sponge; T, Tunicate.

Table 2 (continued)

CLASS Subclass	Order	Family	Family Code	Size	Habitat	Mobility	Feeding Habit	Food
		Hipponicidae	P27	1,2,3,4	Ep	A	F,P	P
		Capulidae	P28	2,3,4	Ep	A	F,P	P
		Calyptraeidae	P29	1,2,3,4	Ep	A	F,P	P
		Cypraeidae	P30	2,3,4,5	Ep	F	G,H	C,D,A
		Ovulidae	P31	1,2	Ep	F	G	C
		Triviidae	P32	1,2	Ep	F	G	T
		Eratoidae	P33	1	Ep	F	G	T
		Lamellariidae	P34	2	Ep	F	G	T
	Aspidophora	Polinicidae	P35	2,3,4	En	F	C	B
		Naticidae	P36	1,2,3,4	En	F	C	B
	Entomostoma	Thiaridae	P37	3,4	F	F	D	D
		Planaxidae	P38	2,3	Ep	F	D	D
		Modulidae	P39	3	Ep	F	H	A
		Diastomidae	P40	1,2	Ep	F	D,H	D,A
		Potamididae	P41	3,4	Ep	F	D	D
		Cerithiidae	P42	2,3,4	Ep,En	F	D	D
		Cerithiopsidae	P43	1	Ep,En	F	G,D	S,D
		Seilidae	P44	1	Ep,En	F	G,d	S,d
	Hamiglossa	Triphoridae	P45	1,2	Ep,En	F	G	S
		Fasciolariidae	P46	3,4	Ep	F	C	B,G
		Nassariidae	P47	2,3,4	Ep	F	S	M
		Buccinidae	P48	1,2,3,4	Ep	F	C,S	B,M
		Pyrenidae	P49	1,2,3	Ep	F	H	A
		Olividae	P50	2,3,4	En	F	C	Po
		Harpidae	P51	4	En	F	C	B
		Marginellidae	P52	1	Ep	F	G	?
		Muricidae	P53	1,2,3,4,5,6	Ep	F	C	B,G,Ci
		Vasidae	P54	5	Ep	F	C	B,Po
		Coralliophilidae	P55	1,2,3	Ep,En	F	P	C
	Toxoglossa	Mitridae	P56	1,2,3,4,5	Ep,En	F	C	Po
		Turridae	P57	1,2,3	Ep,I	F	C	Po
		Conidae	P58	2,3,4,5,6	Ep,En	F	C	Po,G
		Terebridae	P59	2,3,4,5,6	En	F	C	Po
	Heterostropha	Architectonicidae	P60	3,4	Ep	F	P	C
		Toriniidae	P61	2	Ep	F	P	C
	Ptenoglossa	Epitoniidae	P62	1,2,3	Ep	F	P	C
		Janthinidae	P63	3,4	Ep	F	P	C
	Homoeostropha	Eulimidae	P64	1,2,3	Ep,En	F	P	E
Opistobranchia	Entomotaeniata	Pyramidellidae	O1	1,2,3	Ep,En	F	P	C
	Cephalaspidea	Acteonidae	O2	2,3	En	F	D,C	D,B
		Bullidae	O3	3	Ep	F	H	A
		Atyidae	O4	1,2,3	Ep	F	H	A
		Hydatinidae	O5	4	Ep	F	H	A
		Ringiculidae	O6	1	Ep,En	F	D	D
		Scaphanderidae	O7	1,2,3	Ep	F	C	B,Po

Table 2 (continued)

CLASS Subclass	Order	Family	Family Code	Size	Habitat	Mobility	Feeding Habit	Food
		Retusidae	O8	1	Ep,En	F	D	D
		Acteocinidae	O9	1,2	Ep,En	F	D	D
	Acephalaspidea	Aplysidae	O10	3	Ep	F	H	A
	Sacoglossa	Julidae	O11	1	Ep	F	H	A
	Thecosomata	Cavolinidae	O12	1	Ep	F	C	P
Pulmonata		Ellobiidae	PU1	1,2	En	F	H	A
		Siphonariidae	PU2	3,4	En	F	H	A
		Trimusculidae	PU3	1	En	F	H	A
		Lymnaeidae	PU4	2	F	F	H	A
BIVALVIA								
Pterimorphia	Arcoida	Arcidae	PT1	2,3,4	Ep	A	F	P
		Glycymerididae	PT2	2,3,4	En	S	F	P
		Limopsidae	PT3	2,3	En	S	F	P
	Mytiloida	Mytilidae	PT4	3,4	Ep	A	F	P
	Pteroida	Pteriidae	PT5	4,5	Ep	A	F	P
		Isognomonidae	PT6	2,3,4	Ep	A	F	P
		Pectinidae	PT7	2,3,4	Ep	S	F	P
		Spondylidae	PT8	3,4,5	Ep	A	F	P
		Plicatulidae	PT9	3	Ep	A	F	P
		Limidae	PT10	2,3,4,5	Ep	F	F	P
	Ostreina	Ostreidae	PT11	3,4	Ep	A	F	P
Heterodonta	Veneroida	Lucinidae	H1	2,3	En	S	F	P
		Ungulinidae	H2	1,2,3	En	S	F	P
		Chamidae	H3	3,4	Ep	A	F	P
		Montacutidae	H4	1,2,3	En	S,F	F	P
		Galeommatidae	H5	1,2,3	En	S,F	F	P
		Sportellidae	H6	3	En	S	F	P
		Carditidae	H7	3	Ep	A	F	P
		Cardiidae	H8	2,3,4	En	S	F	P
		Tridacnidae	H9	4,5,6	En	S,A	F	P
		Mesodesmatidae	H10	2,3	En	S	F	P
		Mactridae	H11	2,3	En	S	F	P
		Tellinidae	H12	1,2,3,4,5	En	S	F	P
		Trapeziidae	H13	3,4	En	S	F	P
		Semelidae	H14	2,3	En	S	F	P
		Psammoniidae	H15	3,4,5,6	En	S	F	P
		Veneridae	H16	2,3,4,5	En	S	F	P
		Petricolidae	H17	3	En	S	F	P
	Myoida	Corbulidae	H18	2,3	En	S	F	P
		Hiatellidae	H19	2	En	S	F	P
		Lyonsiidae	H20	2	En	A,S	F	P
Anomalodesmacea	Pholadomyoida	Myochamidae	A1	1,2	En	S	F	P
SCAPHOPODA								
Solenoconchia	Dentalioida	Dentaliidae	SO1	3,4	En	F	D	D
	Siphonodentalioida	Siphonodentaliidae	SO2	2	En	F	D	D

Table 3. Numbers of species (S) and those of individuals (N) of 123 families for seven samples, two and five of which were collected by beachcombing and sand-sorting, respectively.

Family	B-1		B-2		S-1		S-2		S-3		S-4		S-5	
Code	S	N	S	N	S	N	S	N	S	N	S	N	S	N
PL1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
C1	1	9	1	14	1	3	0	0	1	4	2	8	1	2
C2	0	0	1	1	1	43	1	11	2	25	1	12	1	2
C3	1	11	1	3	1	1	0	0	0	0	0	0	0	0
S1	1	1	6	6	3	45	4	6	5	5	5	5	3	3
S2	0	0	1	1	1	5	3	4	2	2	1	1	0	0
S3	0	0	3	11	1	3	1	4	3	3	1	1	2	4
S4	0	0	0	0	1	2	0	0	0	0	1	1	0	0
S5	5	60	2	12	1	1	0	0	0	0	0	0	0	0
P1	0	0	1	2	3	24	3	21	4	10	3	5	5	17
P2	4	26	1	13	6	40	1	18	2	6	1	4	1	1
P3	0	0	0	0	1	1	0	0	2	2	1	1	0	0
P4	0	0	0	0	0	0	3	3	3	3	2	4	2	3
P5	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P6	9	108	10	43	7	31	2	10	7	8	7	7	4	56
P7	4	26	1	1	7	41	1	2	2	12	1	3	0	0
P8	4	15	3	9	1	4	1	1	1	1	2	3	0	0
P9	1	18	1	9	0	0	0	0	0	0	0	0	0	0
P10	5	28	7	147	3	53	3	8	4	8	1	1	4	16
P11	2	8	2	4	2	2	1	1	0	0	0	0	1	1
P12	0	0	0	0	8	80	6	25	3	6	4	5	3	6
P13	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P14	0	0	0	0	0	0	0	0	1	1	0	0	0	0
P15	2	7	4	16	1	3	2	3	0	0	1	2	0	0
P16	0	0	0	0	2	8	1	1	1	1	0	0	0	0
P17	5	14	8	23	21	420	20	607	14	390	18	191	10	233
P18	0	0	0	0	4	107	5	34	2	18	2	6	1	1
P19	0	0	0	0	2	120	1	28	1	5	2	5	0	0
P20	1	5	2	5	0	0	0	0	0	0	0	0	0	0
P21	0	0	0	0	0	0	0	0	0	0	1	1	0	0
P22	7	21	1	1	1	1	2	2	1	1	0	0	0	0
P23	2	9	1	2	0	0	0	0	0	0	0	0	0	0
P24	4	10	0	0	0	0	0	0	0	0	0	0	0	0
P25	0	0	0	0	4	12	1	1	2	2	3	3	0	0
P26	7	101	3	33	5	12	2	9	2	3	4	4	2	2
P27	0	0	2	9	1	2	1	13	3	21	11	21	2	62
P28	0	0	0	0	1	3	0	0	1	2	2	4	1	3
P29	2	9	3	5	2	13	1	1	1	1	1	1	0	0
P30	32	457	19	98	1	1	1	1	1	1	1	1	0	0
P31	0	0	2	2	0	0	0	0	0	0	0	0	0	0
P32	2	37	3	26	3	14	3	5	0	0	1	1	1	2

Table 3 (continued)

Family	B - 1		B - 2		S - 1		S - 2		S - 3		S - 4		S - 5	
Code	S	N	S	N	S	N	S	N	S	N	S	N	S	N
P33	0	0	0	0	2	137	1	15	1	12	1	9	1	3
P34	0	0	0	0	0	0	0	0	1	1	0	0	0	0
P35	6	16	4	11	0	0	0	0	0	0	0	0	1	1
P36	3	108	3	21	3	12	3	6	0	0	1	5	2	7
P37	4	24	2	6	2	6	0	0	0	0	0	0	1	2
P38	0	0	1	3	2	7	2	2	0	0	1	1	1	1
P39	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P40	0	0	0	0	1	1	0	0	3	3	3	3	1	5
P41	2	2	0	0	0	0	0	0	0	0	0	0	1	1
P42	16	167	12	60	14	90	16	119	12	67	13	57	10	68
P43	0	0	1	1	12	40	11	48	16	22	7	11	1	1
P44	0	0	1	1	1	2	2	2	1	1	0	0	1	1
P45	11	32	21	107	48	732	39	270	38	144	26	67	14	23
P46	1	2	1	1	0	0	0	0	0	0	0	0	0	0
P47	10	83	6	14	0	0	0	0	0	0	0	0	1	1
P48	12	59	5	18	0	0	0	0	0	0	0	0	1	1
P49	5	13	15	51	17	234	17	112	19	82	18	38	7	8
P50	7	94	6	37	2	26	2	9	2	8	2	12	1	3
P51	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P52	0	0	0	0	5	101	3	21	3	8	3	6	2	6
P53	20	82	18	106	3	4	5	8	6	6	2	2	0	0
P54	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P55	1	7	3	8	1	4	2	2	2	3	2	2	0	0
P56	27	79	21	109	1	2	6	10	4	7	3	3	2	4
P57	9	15	42	76	46	274	61	94	29	33	22	23	20	27
P58	19	58	17	65	0	0	2	2	0	0	0	0	1	1
P59	0	0	2	2	0	0	0	0	0	0	0	0	0	0
P60	0	0	2	3	0	0	0	0	0	0	1	1	0	0
P61	4	18	2	7	2	9	2	6	1	1	2	2	0	0
P62	0	0	2	2	4	5	3	3	8	13	4	4	1	1
P63	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P64	0	0	3	15	1	1	10	34	10	31	10	15	2	17
O1	5	45	9	32	12	24	17	23	15	19	9	9	6	20
O2	1	5	1	1	0	0	0	0	0	0	0	0	0	0
O3	1	3	0	0	0	0	0	0	0	0	0	0	0	0
O4	3	5	2	2	5	35	3	7	7	21	8	14	3	5
O5	2	6	1	1	0	0	0	0	0	0	0	0	0	0
O6	0	0	0	0	1	72	1	11	1	7	1	10	0	0
O7	0	0	1	3	1	1	0	0	2	4	0	0	0	0
O8	0	0	0	0	1	4	1	1	0	0	2	4	0	0
O9	0	0	1	1	7	90	2	28	3	17	3	11	2	33
O10	0	0	0	0	0	0	0	0	1	1	0	0	0	0

Table 3 (continued)

Family	B-1		B-2		S-1		S-2		S-3		S-4		S-5	
Code	S	N	S	N	S	N	S	N	S	N	S	N	S	N
O11	0	0	1	1	2	5	1	2	2	4	1	1	1	1
O12	0	0	0	0	1	1	0	0	0	0	0	0	0	0
PU1	3	7	2	8	0	0	1	2	0	0	0	0	2	2
PU2	3	94	2	24	3	79	1	7	2	5	1	7	0	0
PU3	0	0	1	2	1	68	1	9	1	27	1	7	0	0
PU4	1	1	0	0	0	0	0	0	0	0	0	0	0	0
PT1	0	0	4	28	1	8	4	24	5	54	5	24	2	2
PT2	0	0	0	0	2	17	2	6	2	16	2	12	0	0
PT3	0	0	1	1	0	0	0	0	0	0	0	0	0	0
PT4	2	8	2	23	1	1	2	2	3	13	2	5	1	1
PT5	1	2	1	3	0	0	0	0	0	0	1	2	0	0
PT6	1	2	1	14	1	2	0	0	1	1	1	1	1	1
PT7	4	10	2	3	1	4	3	3	3	3	3	3	0	0
PT8	2	2	2	2	5	0	0	0	0	0	1	1	0	0
PT9	0	0	1	4	0	0	1	3	1	7	1	5	0	0
PT10	0	0	3	4	1	9	2	2	2	2	2	2	0	0
PT11	0	0	1	1	0	0	0	0	0	0	0	0	0	0
H1	0	0	3	9	2	6	1	4	3	11	2	14	1	1
H2	3	13	0	0	1	9	2	5	1	13	1	3	0	0
H3	0	0	3	24	1	1	1	3	1	5	1	3	0	0
H4	2	4	0	0	0	0	0	0	0	0	0	0	0	0
H5	7	29	3	3	3	6	2	4	5	8	5	6	2	2
H6	0	0	0	0	1	1	0	0	0	0	0	0	0	0
H7	0	0	1	1	1	1	1	1	0	0	0	0	2	4
H8	3	3	1	1	1	10	2	2	1	1	1	1	2	4
H9	0	0	1	3	0	0	0	0	0	0	0	0	0	0
H10	0	0	1	1	0	0	0	0	0	0	0	0	0	0
H11	0	0	1	1	1	6	0	0	1	2	1	1	0	0
H12	10	52	5	19	3	42	4	10	4	39	3	24	1	1
H13	0	0	0	0	1	2	1	1	0	0	0	0	0	0
H14	1	1	0	0	1	17	0	0	1	1	0	0	0	0
H15	1	5	2	3	0	0	0	0	0	0	0	0	0	0
H16	2	12	14	80	5	34	5	9	8	78	7	43	6	13
H17	0	0	1	1	0	0	0	0	0	0	0	0	0	0
H18	0	0	1	1	1	2	0	0	0	0	0	0	0	0
H19	0	0	0	0	0	0	0	0	1	5	0	0	0	0
H20	0	0	0	0	0	0	0	0	1	4	1	1	1	2
A1	0	0	0	0	1	8	0	0	1	5	1	5	0	0
SC1	2	17	1	1	0	0	0	0	1	1	0	0	0	0
SC2	1	3	0	0	0	0	0	0	1	1	1	1	0	0
Total	325	2174	356	1529	336	3389	318	1751	308	1358	259	781	153	695

Table 4. Percentage of the number of individuals sorted by subclass in each sample.

CLASS	Subclass	B-1	B-2	S-1	S-2	S-3	S-4	S-5
POLYPLACOPHORA		0.0	0.0	0.0	0.0	0.0	0.0	0.0
GASTROPODA	Cyclobranchia	2.8	1.2	1.4	0.6	2.3	2.7	0.4
	Scutibranchia	2.8	2.0	1.7	0.8	0.8	1.0	1.0
	Pectinibranchia	81.1	76.7	80.2	88.9	69.5	68.4	84.3
	Opistobranchia	2.9	2.7	6.8	4.1	5.4	6.3	8.5
	Pulmonata	4.7	2.2	4.3	1.0	2.4	1.7	1.3
BIVALVIA	Pterimorphia	1.1	5.6	1.2	2.3	7.1	7.0	0.6
	Heterodonta	5.5	9.6	4.1	2.2	12.3	12.3	3.9
	Anomalodesmacea	0.0	0.0	0.2	0.0	0.4	0.6	0.0
SCAPHOPODA		0.9	0.0	0.0	0.0	0.0	0.1	0.0

Table 5. Percentage of the number of individuals sorted by habitat in each sample.

Habitat Type	B-1	B-2	S-1	S-2	S-3	S-4	S-5
Epiphytic in inter/sub-tidal zone	87.1	93.1	88.3	94.1	92.9	92.2	96.1
Endophytic in inter/sub-tidal zone	11.4	5.4	8.0	3.7	5.7	6.7	3.5
Interstitial in inter/sub-tidal zone	0.0	0.0	3.1	1.9	1.3	0.3	0.1
Planktonic in the sea	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Epiphytic in supra-tidal zone	0.3	1.0	0.3	0.2	0.1	0.3	0.0
Epiphytic in fresh/brackish water	1.1	0.4	0.1	0.0	0.0	0.0	0.2

Table 6. Percentage of the number of individuals sorted by mobility in each sample.

Mobility	B-1	B-2	S-1	S-2	S-3	S-4	S-5
Free living	93.0	84.1	94.2	94.8	78.6	77.0	86.2
Stationary	5.9	8.3	4.9	2.5	13.7	14.4	3.3
Attaching to substrata	1.1	7.6	0.9	2.7	7.7	8.6	10.5

Table 7. Percentage of the number of individuals sorted by feeding habit in each sample.

Feeding habit	B-1	B-2	S-1	S-2	S-3	S-4	S-5
Herbivore	23.9	27.1	24.6	15.2	16.8	17.0	18.6
Grazer of colonial amimals	24.2	15.4	30.3	20.7	13.9	12.2	5.2
Carnivore	25.5	29.6	9.5	7.5	4.3	5.9	6.3
Scavenger	3.8	0.9	0.0	0.0	0.0	0.0	0.1
Detritus feeder	12.2	6.5	27.1	47.4	38.4	37.4	50.5
Filter feeder	7.0	16.0	6.1	5.3	21.6	23.3	13.8
Parasite	3.3	4.4	2.4	3.9	4.9	4.2	5.5
Symbiotic with zooxanthellae	0.1	0.1	0.0	0.0	0.0	0.0	0.0

Table 8. Percentage of the number of individuals sorted by their food in each sample.

Food	B-1	B-2	S-1	S-2	S-3	S-4	S-5
Algae	23.9	27.1	24.6	15.2	16.8	17.0	18.6
Sponge	1.5	7.1	22.8	18.3	12.3	10.0	3.6
Cnidaria	3.3	3.5	1.2	1.9	2.7	2.3	3.0
Polychaeta/ Sipuncula/ Nematoda	17.9	34.1	17.5	12.3	23.9	25.6	10.4
Gastropoda (Mollusca)	3.8	6.9	0.1	0.5	0.4	0.3	0.0
Bivalvia (Mollusca)	8.8	3.6	0.4	0.3	0.3	0.6	1.3
Echinodermata	1.8	1.2	1.2	2.1	2.4	1.9	2.4
Tunicata (Prochordata)	1.7	1.7	2.5	1.1	1.0	1.3	0.7
Detritus	33.0	12.9	27.2	47.5	38.5	37.5	50.5
Plankton	0.5	0.9	0.6	0.8	1.8	3.5	9.3
Dead or decaying animal matters	3.8	0.9	0.0	0.0	0.0	0.0	0.1

herbivores and parasites were roughly similar among the 7 samples, whereas that of "grazer of colonial animals" in S - 5 was much lower than in other samples.

Table 8 shows shell composition along with different food menus. The percentage of mollusc feeders, e.g., Naticidae, Muricidae and Vasidae, was higher in the beachcombing samples than in the sand-sorting samples. In contrast, the percentages of sponge feeders, e.g., Cerithiidae, Cerithiopsidae and Triphoridae, were lower in the beachcombing samples than those in sand-sorting samples, excluding S - 5.

Next, the data on the shell assemblages of the 7 samples (Table 3) were standarized and used for principal component analysis; Fig. 2 and Fig. 3 show the results. The first intersample gradient involved variation in the sampling methods (first principal component, PCl , 40.9 % of variance). High positive loads on PCl ($>$ 1.3) were observed in the variables of composition of Muricidae, Psammoniidae, Polinicidae, Buccinidae, Colubrariidae, Calyptraeidae, Vanicoroidae and Acteonidae (Fig. 3). High negative loads on PCl ($< -$ 1.0) were in Eulimidae, Turbinidae, Rissoidae, Julidae, Glycymeridae and Acmaeidae (Fig. 3). Shells of the former families were generally larger than those of the latter ones.

The second inter-sample trend was related with sampling dates (second principal component, PC2, 24.1 % of variance); the samples in 1988 had lower PC2 than those in 1979. High positive loads on PC2 ($>$ 1.4) were observed in the variables of composition of Umboniidae, Liotiidae, Calyptraeidae, Ellobiidae, Semelidae, Veneridae, Corbulidae, Assimineidae, Rissoellidae, Sportellidae, Emarginulidae, Tornidae, Caecidae, Cavolinidae, Triphoridae and Trapeziidae. High negative loads on PC2 ($< -$ 0.8) were in Phasianellidae, Hipponicidae, Lyonsiidae, Diastomidae and Arcidae (Fig. 3). The trend suggests the following changes in composition of shell assemblages: (1) decrease of interstitial/endophytic detritus feeders, e.g., Caecidae, Tornidae, Rissoellidae Liotiidae and Umboniidae, (2) decrease of "grazers of colonial animals", e.g., Triphoridae and Emarginulidae, (3) decrease of snails inhabiting in supralittoral zone around river mouth, e.g., Ellobiidae and Assimineidae, and (4) increase of filter feeders which attaches to substrata, e.g., Hipponicidae, Lyosiidae and Arcidae.

In sand-sorting samples in 1988, S - 5 (the sample at site D which located near the construction of a new airport) had the lowest PC2, and increasing order are S - 4, S - 3, S - 2 (Fig. 2). Thus, the trend between the years coincides with the gradient of environmental disturbance and suggests that the change in composition of the shell assemblages might be resulted from deterioration of the coral reef ecosystem, caused by construction of the airport.

Discussion

Waves and water currents selectively transport diverse shells on the shoreline, and provide a shell assemblage among beach material. The various sized shells can be sampled by the two methods: beachcombing of shells of moderate and large size and sand-sorting of those of minute size. Though we still do not understand well the process of selective transportation, we can compare samples of the same season of different years as long as the geologial and physical environment which determined the selective transportation remains unchanged.

In this report, the molluscan shell assemblages on the shoreline were quantitatively analyzed, and temporal changes of them were detected. The principal compo-

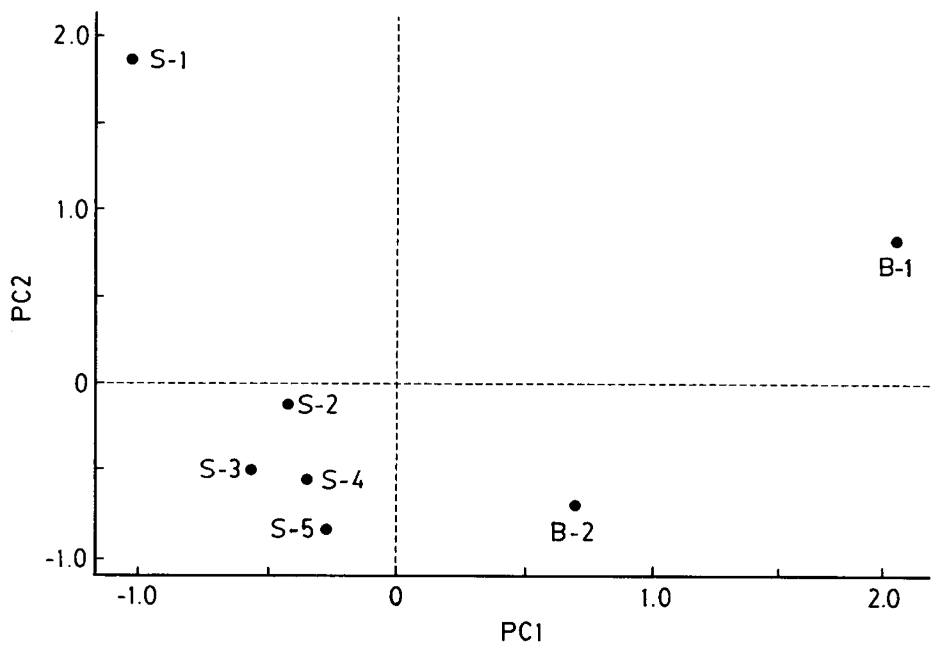

Fig. 2. Distributions of shell assemblages of seven samples over the plane defined by the first (PC1) and second principal components (PC2) resulting from the correlation matrix for variables of the number of shells per family. Factor loadings of PC1 and PC2 are shown in Fig. 3.

nent analysis of the shell assemblages detected two major components: the first was in variation in sampling methods, and the second was that in sampling years. The first trend is mainly due to the difference of size distribution of shells. The second trend was related not only to the sampling dates of both beachcombing and sand-sorting samples, but also to the environmental gradient in sand-sorting samples (Figs. 1 and 2). This trend suggests that the change in the composition of molluscan shell assemblages may be due to environmental disturbance.

Then, I discuss effect of disturbance of coral reef ecosystem on changes in molluscan community. The construction of the new airport caused silt sedimentation and decrease of live corals. Silt sedimentation accompanied by reclamation will bring ab-

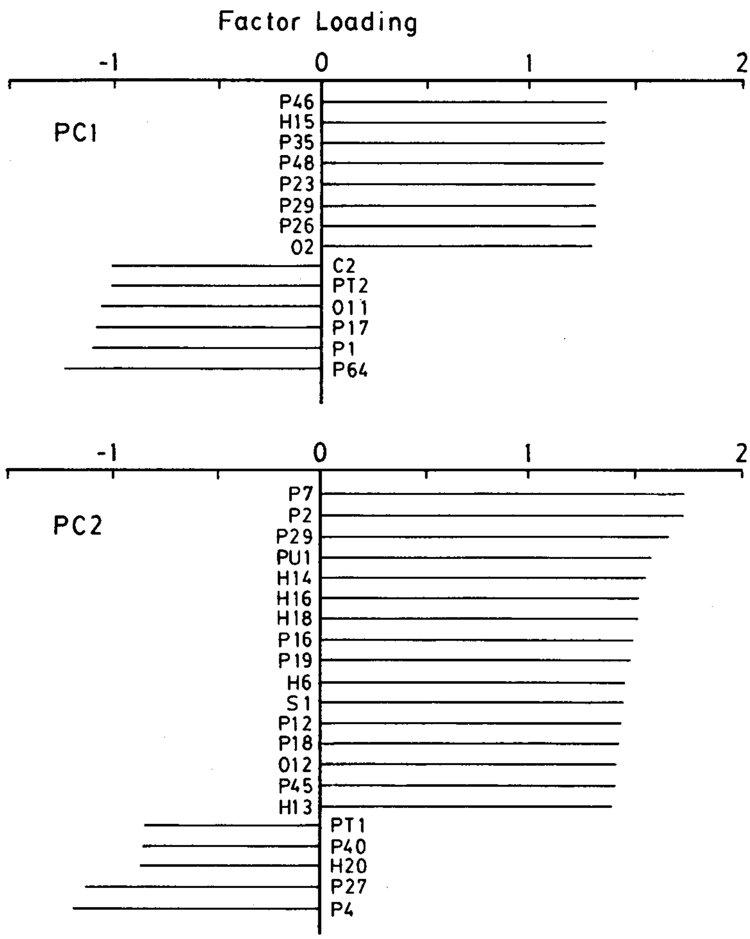

Fig. 3. Factor loading of PC1 and PC2 derived from the principal component analysis of the data on shell assemblages of seven samples. Only loadings > 1.3 or <− 1.0 for PC1 and > 1.4 or < − 0.8 for PC2 were shown. Cumulative proportion of variance at PC2 is 64.9 %.

out changes of benthic community of lagoon: (1) decrease of some kinds of benthic microorganisms, e.g., benthic foraminifera (Frerichs, 1970), and (2) decrease of some kinds of grazers and suspension feeders (Nishihira, 1981). Thus, the decrease of interstitial/endophytic detritus (including foraminifera) feeders, e.g., Caecidae, Tornidae, Rissoellidae, Liotiidae and Umboniidae and the decrease of "grazers of sponge", e.g., Triphoridae and Emarginulidae are thought to be due to the silt sedimentation.

Decrease of live corals accompanied by silt sedimentaiton will also change the benthic community of a lagoon. Nishihira et al (1974) briefly reported that the catastrophic predation of corals by *Acanthaster* resulted in the remarkable change of the community structure such as an increase of the filamentous and calcareous algae, cryptobion and hypobion. Because there are few molluscan species that feed on reef-building corals, the abrupt decrease of corals does not directly result in the decrease of some kinds of molluscs. The decrease of live corals will offer intact substrata to the sedentary organisms. The increase of turbidity-tolerant filter feeders that attach to substrata, e.g., Hipponicidae and Arcidae, may be related with the increase of intact substrata of dead corals.

As the coastal environment is being changed drastically by human impact, it is an urgent necessity to survey the long term changes in abundance and community structure of marine organisms. Beachcombing and sand-sorting of shells washed up on the shore are thought to be novel methods for long term survey, though it is still necessary to clarify the relationship between the shell assemblages washed up on the shore and the real molluscan community in the sea.

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